Geographic variation in the volatile leaf oils of *Juniperus excelsa* and *J. polycarpos*

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ABSTRACT

Analyses of *J. excelsa* revealed the volatile leaf oils from Bulgaria and Greece were higher in α-pinene, limonene and β-phellandrene than populations from Turkey, Cyprus and Lebanon. Otherwise, there was little variation in the oils between these populations. Cedrol was a major component in each of the populations, ranging from 22.6 to 29.3%. Analyses of *J. polycarpos* var. *polycarpos* from Azerbaijan revealed the presence of high cedrol and zero cedrol chemotypes. The high cedrol chemotype was similar to the oil from Armenia. The Azerbaijan zero cedrol chemotype was similar to the oil from El Njass, Lebanon. The compositions of oils of *J. polycarpos* var. *turcomanica* and *J. seravschanica* were compared with the oils of *J.* excelsa and *J. polycarpos* var. *polycarpos*. Published on-line: **www.phytologia.org** *Phytologia 96(2): 96-106 (April 1, 2014)*. ISSN 030319430

KEY WORDS: *Juniperus excelsa, J. polycarpos* var. *polycarpos, J. polycarpos* var. *turcomanica, J. seravschanica,* geographic variation, leaf oils, terpenes, cedrol, α-pinene, limonene.

Adams et al. (2013) recently examined geographic variation in *J. excelsa* and reviewed the leaf essential oil literature. They found *J. excelsa* oils from Bulgaria and Greece to have lower α-pinene (24.3, 21.6%) than oils from Turkey and Cyprus (41.7, 41.8%) plus many other quantitative differences. Cedrol was present at 25.4 to 29.3% in each population and ranged from 11.3% to 35.8% in all 12 trees examined.

The oils of *J. polycarpos* var. *polycarpos*, *J. p.* var. *turcomanica* and *J. p.* var. *seravschanica* (now *J. seravschanica*) have been the subject of several studies by Adams et al. (2008). Initial reports on *J. polycarpos* (Adams 2001; Adams et al. 2008) oils from Armenia (Lake Sevan) were high in α-pinene and cedrol. Recently, Adams and Hojjati (2013) analyzed the leaf essential oils of *J. polycarpos* var. *turcomanica* and *J. seravschanica* from central and southern Iran and included analyses of *J. polycarpos*, (Armenia) and *J. excelsa* (Eskisehir, Turkey).

The distributions of *J. excelsa* and *J. polycarpos* (stricto sensu) are shown in Figure 1. It is difficult to distinguish these taxa and they have been treated as conspecific (Farjon, 2005, 2010; Douaihy et al, 2011). Douaihy et al. (Fig. 4, 2011), using 3 microsatellites, found the *J. excelsa* ordinated into 3

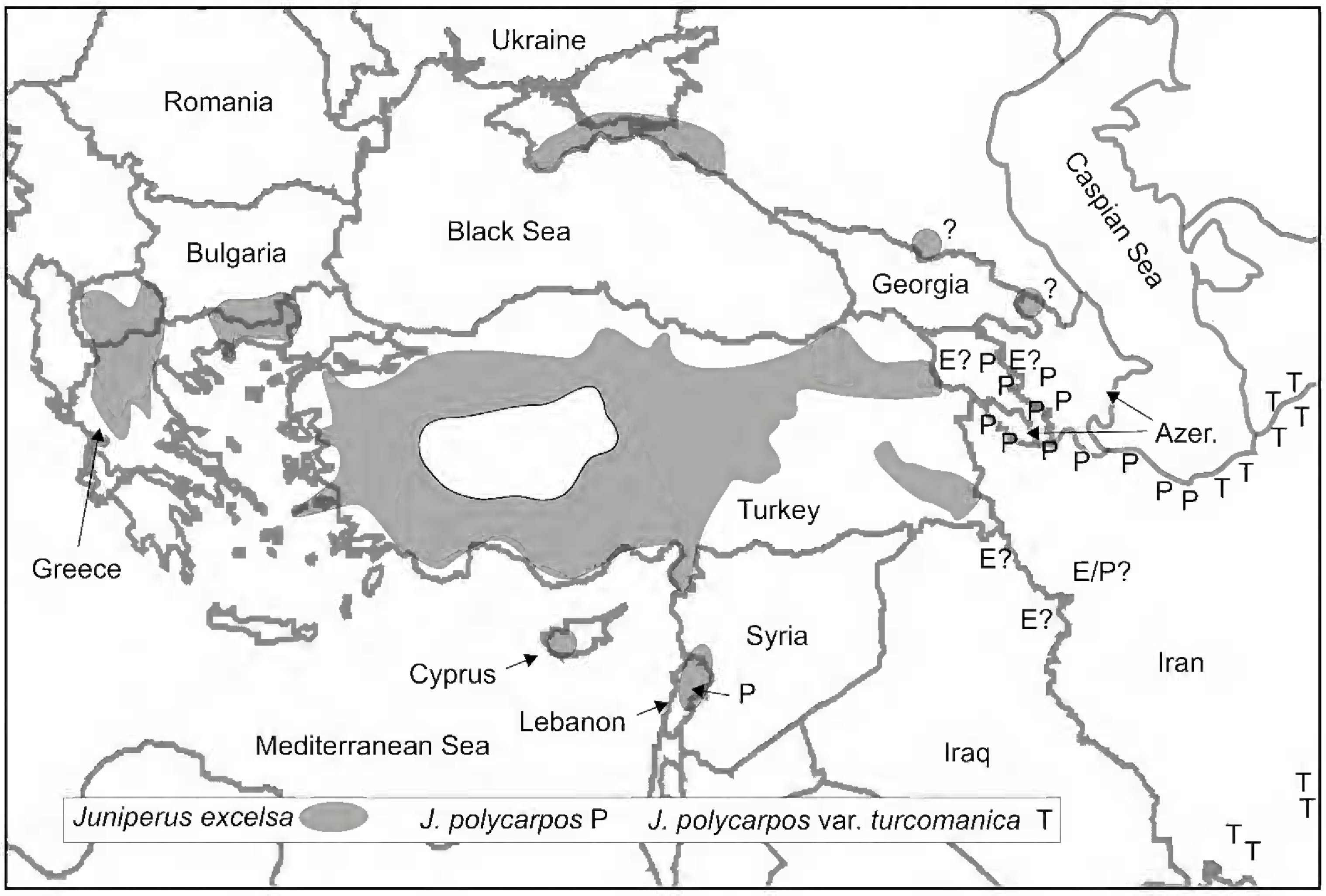

Figure 1. Distribution of *J. excelsa*, *J. polycarpos* var. *polycarpos and J. p.* var. *turcomanica* (modified from Adams (2014). Questionable populations of *J. excelsa* and *J. polycarpos* are indicated by E? and P?.

groups: Greece, Ukraine (Crimea), Turkey, Crete; Lebanon (moderate elevations: Qammouaa, Danniyeh, Barqa, Afqa) and Lebanon (two very high elevations, Aarsal 2180 m; El Njass 2287 m). Recently, Adams et al. (2014), using 4430 bp of DNA seqeunce data, have shown that the trees at Afqa, 1307 m, are *J. excelsa* and the trees at El Njass, 2287 m, are *J. polycarpos,* but appearing intermediate to *J. p.* var. *turcomanica*.

Recently, leaf materials suitable for distillation were obtained of *J. excelsa* and *J. polycarpos* from Lebanon and *J. polycarpos* from Azerbaijan. This afforded the opportunity to further examine geographic variation in the volatile leaf oils of both *J. excelsa* and *J. polycarpos.*

MATERIALS AND METHODS

Plant material -

J. excelsa: Eskisehir, Turkey, 820m, *Adams 13193 (9433-9435),* Bulgaria, 356 m, *Adams 14056 (13720-13724), Alex Tashev, 2012-1-JE -5-JE*, 42° 01' 22.0" N; 24° 28' 03.1" E, Central Rhodopes, above the town of Kritchim, Reserve "Izgorialoto Gune"; Lemos, Greece, 1100m, *Adams 6031 (5983-5985,* *5987*), Cyprus, *Adams 13487*, *A. K. Christou s.n.*, bulk 5 trees; Afqa, Lebanon, 1306 m, *Adams 14155-14157*, *Bouchra Douaihy 1-3*, 34° 04' 58.12"N, 35° 53' 08.52"E, 4 Nov 2013,

J. polycarpos: Armenia, Lake Sevan, 1900 m, *Adams 13194 (8761-8763)*; Azerbaijan, 177-231m, *Adams 14162-14171, Vahid Farzaliyev 1-10*, 40° 74' 47.6" N; 40° 58' 55" E, Dec 2013; Lebanon, Danniyeh-Wadi El Njass, 2287 m, *Adams 14158-14161*, *Bouchra Douaihy 4-7*, 34° 20' 47.79"N, 36° 05' 45.54"E, 14 Nov 2013.

J. polycarpos var. *turcomanica*: *Adams 13197 (8758-90),* Kopet Mtns., Turkmenistan;

J. seravschanica: *Adams 13195 (8483-85)*, Pakistan.

Voucher specimens deposited in the Herbarium, Baylor University (BAYLU).

Fresh or air dried (100 g) leaves were steam distilled for 2 h using a circulatory Clevenger-type apparatus (Adams, 1991). The oil samples were concentrated (diethyl ether trap removed) with nitrogen and the samples stored at -20° C until analyzed. The extracted leaves were oven dried (48h, 100° C) for the determination of oil yields. The oils were analyzed on a HP5971 MSD mass spectrometer, scan time 1/ sec., directly coupled to a HP 5890 gas chromatograph, using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column (see Adams, 2007 for operating details). Identifications were made by library searches of our volatile oil library (Adams, 2007), using the HP Chemstation library search routines, coupled with retention time data of authentic reference compounds. Quantitation was by FID on an HP 5890 gas chromatograph using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column using the HP Chemstation software.

RESULTS AND DISCUSSION

The compositions of the leaf oils for the five populations of *J. excelsa* are given in Table 1. The major components of the oils are cedrol (22.6 - 29.3%), α-pinene (21.6 - 41.8%, limonene (0.5 - 13.3%,) and β-phellandrene (0.4 - 9.2%). The oils from Bulgaria and Greece are higher in α-pinene, limonene and β-phellandrene than populations from Turkey, Cyprus and Lebanon. Otherwise, there was little variation in the oils between these populations of *J. excelsa*. Variation in cedrol among *J. excelsa* trees, ranges from 11.3% (Eshisehir, Table 2) to 35.8% (Greece, Table 2). In contrast to *J. polycarpos* (see below) where all trees contained considerable amounts of cedrol (and associated cedarwood oil components).

The leaf oil of *J. polycarpos* (El Njass, Lebanon) is included in Table 1 and it's oil differs from *J. excelsa* by lacking the typical cedarwood compounds α-cedrene β-cedrene, thujopsene, cuparene, cedrol, widdrol, etc. (Adams, 2014). In addition, *J. polycarpos* has a larger concentration of α-pinene (55.6%), plus (4Z)-decen-1-ol, (E)-caryphyllene, α-muurolene, γ-cadinene, elemol, germacrene B, germacrene D-4-ol, junenol, epi-α-cadinol, epi-α-muurolol, α-murrolol, α- and β-eudesmols and shyobunol.

Analyses of *J. polycarpos* var. *polycarpos* from Azerbaijan revealed the presence of high cedrol and low (trace amounts) cedrol (and cedarwood components) chemotypes. Most *Juniperus* species produce two kinds of essential oils: leaf oils and heartwood oils and these oils have few components in common (Adams, 1991). *Juniperus excelsa*, along with *J. foetidissima, J. polycarpos,* and *J. seravschanica* have leaf oils that contain significant amounts of the heartwood oil components (cf. α-cedrene β-cedrene, thujopsene, cuparene, cedrol, widdrol, etc., see Adams, 2014). For example, Adams (1990) reported 4.4, 0.2, trace and 8.3% cedrol in the leaf oils from four trees of *J. foetidissima* from Greece. Whereas, Tunalier et al. (2004) reported 13.0 and 12.2% of cedrol and widdrol in the stem heartwood of *J. foetidissima* from Turkey. Ucar and Balaban (2002) analyzed the sapwood (white wood) of *J. excelsa*, Turkey, and reported the oil to contain 22.5% widdrol and 9.0% cedrol (these components are difficult to separate on non-polar columns and the mass spectra are nearly identical, so their identification is often problematic).

When *Juniperus* species contain heartwood components in the leaf oils, it is common to find chemical polymorphisms in cedrol (and associated heartwood terpenes) between trees. That is the case for *J. polycarpos* from Azerbaijan with cedrol in five trees ranging from 24.8 to 34.4% (hi cedrol chemotype, Table 3) and the cedrol of five other trees ranging from 0.00 to 0.03% (low cedrol chemotype, Table 3). The samples from Armenia ranged from 26.0 to 34.3% in cedrol. In the trees from El Njass, Lebanon, cedrol ranged from 0.00 to 0.01%. Trace amounts of cedrol may be due to free radical interactions rather than enzyme based reactions (or even cross-contamination during distillation, and GC analysis). It is interesting that in trees of *J. p.* var. *turcomanica* from Turkmenistan, only trace amounts of cedrol were found (Table 4), but in a population from Fasa, Iran, two chemotypes were found (0.00 to 0.1%, and 10.1, 13.8%, Table 4). Adams and Hojjati (2013) found *Juniperus* in the Fasa area to be quite variable and it seems likely that some of the samples are hybrids or introgressants with *J. p.* var. *polycarpos* in that population (see Adams, Hojjati and Schwarzbach, 2014 for DNA analyses).

Geographic variation in the leaf terpenoids of *J. polycarpos* is difficult to assess due to the high and low cedrol chemotypes in populations. The compositions of the leaf oils for the four populations of *J. polycarpos* are given in Table 4. The Azerbaijan high cedrol chemotype oil was similar to the high cedrol oil from Armenia (Table 4). The Azerbaijan low cedrol chemotype was similar in composition to the low cedrol oil from El Njass, Lebanon. The higher concentrations of several major compounds in El Njass and Azerbaijan, low cedrol) oils seems to be explained by the presence of cedrol (and other cedarwood compounds) in the high cedrol oils of Azerbaijan and Armenia. For example, removing the cedrol and other cedarwood components from Azerbaijan and Armenia, high cedrol oils, shows the revised concentrations of α-pinene, germacrene B and shyobunol to be quite similar (Table 5) to that found in El Njass and Azerbaijan (low cedrol). However, the correction for cedarwood oil components was not sufficient to produce uniform levels for δ-cadinene, germacre-4-ol, and α-eudesmol (Table 5). It appears the terpene synthase genes for production of cedrol (and related compounds) interferes with the production of some other compounds (cf. δ-cadinene, germacre-4-ol, and α-eudesmol) between Azer lo ced and Azer hi ced, Table 5).

The low-cedrol leaf oils of *J. polycarpos* var. *polycarpos* (Njass, Azerbaijan) and *J. p.* var. *turcomanica* are nearly identical in compositions. (Table 4). DNA sequence data (Adams et al., 2014) showed the El Njass trees to be somewhat intermediate between *J. polycarpos* var. *polycarpos* and *J. p.* var. *turcomanica*. This is shown in α-pinene as it is intermediate in concentration. The oil of El Njass does show complementary amounts for some terpenes (var. *turcomanica*, El Njass, var. *polycarpos*): δ-3-carene (t, 2.1, 2.3); terpinolene (0.8, 0.8, 1.2); trans-verbenol (0, 0.4, 0.8); 4Z-decen-1-ol (0, 0.2, 0,2); β-elemene (0.2, 0.2, 0); epi-cubebol (0.5, 0.5, 0); germacrene D-4-ol (8.9, 4.0, 3.7); junenol (0, 0.5, 0.2); α-cadinol (3.6, 1.1, 0.8); manoyl oxide (0, 0.6, 0.2) and 4-epi-abietal (1.9, 0.7, 0.9). Additional research on the relationship of the El Njass trees to *J. polycarpos* var. *polycarpos* and *J. p.* var. *turcomanica* should prove interesting.

In spite of the presence or absence of cedarwood components in the leaf oils in some populations of *J. polycarpos* var. *polycarpos*, there appear to be only minor geographical differences in the leaf oils. The leaf oil of *J. p.* var. *turcomanica* is most similar to the low cedrol oils found in El Njass and Azerbaijan (Table 4).

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LITERATURE CITED

Adams, R. P. 1990. The volatile leaf oil of *Juniperus foetidissima* Willd. from Greece and comparisons with oils from Turkey and the Crimea, USSR. J. Essent. Oil Res. 2:67-70.
Adams, R. P. 1991. Cedar wood oil - analysis and properties. In Modern Methods of Plant Analysis: Oils and Waxes. Edits., H. F. Linskins and J. F. Jackson, pp. 159 - 173, Springler-Verlag, Berlin, Germany.
Adams, R. P. 2001. Geographic variation in leaf essential oils and RAPDs of *J. polycarpos* K. Koch in central Asia. Biochem. Syst. Ecol. 29: 609-619.
Adams, R. P. 2007. Identification of essential oils by gas chromatography/ mass spectrometry, 4th edition. Allured Publ., Carol Stream, IL, USA.
Adams, R. P. 2013. Correction to Adams and Schwarzbach, Taxonomy of the multi-seeded, entire leaf taxa of the *Juniperus*, section *Sabina*: sequence analysis of nrDNA and four cp DNA regions. Phytologia 95: 226-227.
Adams, R. P. 2014. The junipers of the world: The genus *Juniperus*. 3rd ed. Trafford Publ., Victoria, BC.
Adams, R. P. and F. Hojjati. 2012. Taxonomy of *Juniperus* in Iran: Insight from DNA sequencing. Phytologia 94: 219-227.
Adams, R. P. and F. Hojjati. 2013. Leaf essential oils of *Juniperus* in central and southern Iran. Phytologia 95: 288-295.
Adams, R. P., B. Douaihy, M. D. Dagher-Kharrat, A. E. Schwarzbach and V. Farzaliyev. 2014. Geographic variation in nrDNA and four cpDNAs sequences of *Juniperus excelsa* and *J. polycarpos* in Greece, Turkey. Lebanon and Azerbaijan. Phytologia 96: 89-95.
Adams, R. P., F. Hojjati and A. E. Schwarzbach. 2014. Taxonomy of *Juniperus* in Iran: DNA sequences of nrDNA plus three cpDNAs reveal *Juniperus polycarpos* var. *turcomanica* and *J. seravschanica* in southern Iran. Phytologia 96: 19-25.
Adams, R. P., J. A. Morris and A. E. Schwarzbach. 2008. Taxonomic study of *Juniperus excelsa* and *J. polycarpos* using SNPs from nrDNA and cp trnC-trnD plus essential oils and RAPD data. Phytologia 90: 208-225.
Adams, R. P. and A. E. Schwarzbach. 2012. Taxonomy of the multi-seeded, entire leaf taxa of *Juniperus* section Sabina: Sequence analysis of nrDNA and four cpDNA regions. Phytologia 94: 350-368.
Adams, R. P., A. N. Tashev, K. H. C. Baser and A. K. Christou. 2013. Geographic variation in the volatile leaf oils of *Juniperus excelsa* M.-Bieb. Phytologia 95: 279-285.
Douaihy, B., G., G. Restoux, N. Machon and M. B. Dagher-Karrat. 2013. Ecological characterization of the *Juniperus excelsa* stands in Lebanon. Ecologia Mediterranea 39: 169-180.
Douaihy, B., G., G. Vendramin, A. Boratynski, N. Machon and M. B. Dagher-Karrat. 2011. High genetic diversity with moderate differentiation in *Juniperus excelsa* from Lebanon and the eastern Mediterrean region. AoB PLANTS 2011 pir003 doi:10.1093/aobpla/pir003.
Farjon, A. 2005. A monograph of Cupressaceae and *Sciadopitys*. Royal Botanic Garderns, Kew Press, London.
Farjon, A. 2010. A handbook of the world's conifers. Vol. I. Koninklijke Brill NV, Leiden, The Netherlands.
Tunalier, Z., N. Kirimer and K. H. C. Baser. 2004. A potential new source of cedarwood oil: *Juniperus foeditissima* Willd. J. Essent. Oil Res. 16: 233-235.
Ucar, G. and M. Balaban. 2002. The composition of volatile extractives from the wood of *Juniperus excelsa, Juniperus foetidissima* and *Juniperus oxycedrus*. Holz als Roh- und Werkstoff 60: 356-362.

Table 1. Leaf essential oils from populations of *J. excelsa*. Afqa, Lebanon, *Adams 14155-14157*; Bulgaria: *Adams 13720-13724*; Lemos, Greece: *Adams 5983-5985, 5987,* Eskisehir, Turkey; *Adams 9433-9435* and Cyprus, *Adams 13487* (bulk, 5 trees) and *J. polycarpos*, El Njass, Lebanon, *Adams 14158-14161*. Components that are typical of heartwood oil are highlighted in italics.

		J. excelsa					*polycarpos*
KI	Compound	Kritchim Bulgaria	Lemos Greece	Eskisehir Turkey	Cyprus	Afqa, Lebanon	El Njass Lebanon
921	tricyclene	t	0.1	0.2	0.1	0.1	0.1
932	**α-pinene**	**24.3**	**21.6**	**41.7**	**41.8**	**37.9**	55.6
945	α-fenchene	0.1	0.1	0.3	t	0.5	0.2
946	camphene	0.2	0.3	0.2	0.1	0.2	0.3
953	thuja-2,4(10)-diene	t	t	0.1	t	t	0.1
961	verbenene	t	t	t	t	-	-
969	sabinene	t	0.2	0.1	0.1	t	t
974	β-pinene	0.5	0.5	0.7	0.4	0.6	0.8
988	myrcene	1.4	1.2	1.2	0.5	1.4	1.5
1002	α-phellandrene	t	t	0.1	t	t	t
1008	δ-3-carene	0.8	1.7	5.3	t	10.8	2.1
1014	α-terpinene	t	t	0.1	t	0.1	t
1020	p-cymene	0.5	0.4	0.6	0.1	0.2	0.2
1024	sylvestrene	-	-	-	-	t	-
1024	**limonene**	**11.3**	**13.2**	**1.2**	**0.5**	**0.8**	1.0
1025	**β-phellandrene**	**7.5**	**9.2**	**0.9**	**0.4**	**0.8**	0.7
1044	(E)-β-ocimene	t	t	t	t	t	t
1054	γ-terpinene	0.5	0.4	0.5	0.3	0.4	0.3
1065	cis-sabinene hydrate	t	t	t	t	-	-
1086	terpinolene	0.8	0.7	1.1	0.3	1.9	0.8
1095	linalool	-	-	-	-	t	0.4
1097	trans-sabinene hydrate	t	t	t	t	-	-
1112	3-me-3-butenyl-methyl butanoate	0.4	0.1	t	t	0.1	0.1
1114	endo-fenchol	0.2	0.2	t	t	t	-
1118	cis-p-menth-2-en-1-ol	-	-	0.1	t	-	-
1122	α-campholenal	0.2	0.1	0.5	0.1	0.2	0.2
1135	trans-pinocarveol	0.4	0.2	0.8	0.1	0.2	0.2
1137	trans-verbenol	-	-	0.2	-	-	0.3
1141	camphor	0.7	0.5	1.2	0.2	0.8	0.4
1145	camphene hydrate	t	t	0.1	t	t	0.1
1158	trans-pinocamphone	-	-	-	-	0.1	-
1165	borneol	-	-	-	-	-	0.2
1166	p-mentha-1,5-dien-8-ol	t	t	-	t	t	-
1172	cis-pinocamphone	t	t	0.2	t	t	-
1174	terpinen-4-ol	t	0.2	0.1	0.1	-	t
1178	naphthalene	t	t	0.1	t	-	-
1179	p-cymen-8-ol	t	t	0.1	t	-	-
1186	α-terpineol	t	t	t	t	-	t
1193	(4Z)decenal	-	-	-	-	-	0.2
1195	myrtenol	-	-	-	-	-	0.1
1204	verbenone	t	t	0.2	t	0.1	0.2
1215	trans-carveol	0.2	0.1	0.2	t	0.1	0.1
1218	endo-fenchyl acetate	t	0.2	0.1	t	-	-
1241	hexyl isovalerate	-	-	-	-	-	0.1

		J. excelsa					*polycarpos*
KI	Compound	Kritchim Bulgaria	Lemos Greece	Eskisehir Turkey	Cyprus	Afqa, Lebanon	El Njass Lebanon
1249	piperitone	t	t	0.1	t	0.1	-
1255	(4Z)-decen-1-ol	-	-	-	-	-	0.2
1260	3-me-3-butenol hexanoate	0.2	0.1	-	-	t	-
1274	pregeijerene B	-	-	-	-	-	-
1284	bornyl acetate	t	0.6	0.4	0.1	0.1	0.3
1292	(2E,4Z)-decadienal	t	0.3	0.1	t	-	-
1319	(2E,4E)-decadienol	3.9	3.6	2.4	2.3	3.5	-
1335	δ-elemene	-	-	-	-	-	0.2
1374	α-copaene	-	-	-	-	-	0.1
1387	β-bourbonene	t	0.1	0.1	t	t	0.1
1389	β-elemene	-	-	-	-	-	0.2
1390	7-epi-sesquithujene	0.2	0.1	0.1	0.3	-	-
1410	*α-cedrene*	*1.0*	*1.1*	*0.8*	*1.7*	*1.2*	-
1413	*β-funebrene*	*1.0*	*0.9*	*0.7*	*1.8*	*0.6*	-
1417	(E)-caryophyllene	-	-	-	-	-	0.7
1419	*β-cedrene*	*1.1*	*1.0*	*0.5*	*1.0*	*0.7*	-
1429	*cis-thujopsene*	*0.3*	*0.4*	*0.3*	*0.8*	*0.3*	-
1434	γ-elemene	-	-	-	-	-	0.2
1449	trans-sibirene	-	-	-	-	-	0.2
1451	trans-muurola-3,5-diene	0.2	0.1	0.1	0.7	t	-
1452	α-humulene	0.1	0.2	0.1	0.2	t	0.1
1454	(E)-β-farnesene	0.1	0.2	0.2	0.3	0.1	-
1469	*β-acoradiene*	*0.1*	*0.1*	*0.2*	*0.4*	*0.1*	-
1475	trans-cadina-1(6),4-diene	0.4	0.3	0.2	0.7	0.1	t
1478	γ-muurolene	-	-	-	-	-	0.2
1480	germacrene D	0.8	0.8	0.6	1.2	1.2	1.1
1489	β-selinene	-	-	-	-	-	0.2
1493	trans-muurola-4(14),5-diene	0.6	0.4	0.2	1.5	0.1	-
1493	epi-cubebol	-	-	0.3	-	0.3	0.5
1496	valencene	0.6	0.5	0.3	t	-	-
1500	α-muurolene	-	-	-	-	-	0.4
1500	*β-himachalene*	-	*t*	*0.1*	-	*0.1*	-
1504	*cuparene*	-	*t*	*0.1*	*t*	-	-
1508	germacrene A	-	-	-	-	-	0.2
1506	*(Z)-α-bisabolene*	-	-	*0.1*	*t*	-	-
1512	*α-alaskene*	*0.4*	*0.3*	*0.2*	*0.2*	*0.4*	-
1513	γ-cadinene	-	-	-	-	-	1.4
1514	cubebol	0.8	0.7	0.4	1.2	0.3	-
1521	trans-calamenene	0.5	0.2	0.2	0.5	0.2	-
1522	δ-cadinene	0.5	0.3	0.3	0.6	0.2	1.6
1532	γ-cuparene	0.3	0.2	0.2	0.5	-	-
1537	α-cadinene	-	-	-	-	-	0.3
1548	elemol	-	-	-	-	-	1.2
1559	germacrene B	-	-	-	-	-	3.6
1561	(E)-nerolidol	-	-	-	-	-	0.1
1574	germacrene D-4-ol	-	-	-	-	-	4.0
1582	caryophyllene oxide	-	-	-	-	-	0.3
1589	*allo-cedrol*	*1.7*	*2.0*	*1.9*	*2.4*	*1.4*	-
1594	ethyl decanoate	-	-	-	-	-	0.3
1600	*cedrol*	*25.5*	*29.3*	*25.4*	*27.5*	*22.6*	-

		J. excelsa					*polycarpos*
KI	Compound	Kritchim Bulgaria	Lemos Greece	Eskisehir Turkey	Cyprus	Afqa, Lebanon	El Njass Lebanon
1608	humulene epoxide II	t	t	t	t	t	-
1608	β-oplopenone	t	t	t	t	t	0.4
1618	junenol	-	-	-	-	-	0.5
1622	sesquiterp. 67,134,174,202	-	-	-	-	-	1.0
1627	1-epi-cubenol	0.8	0.7	0.5	0.7	t	-
1630	γ-eudesmol	-	-	-	-	-	03
1632	*β-acorenol*	*t*	*0.1*	*0.1*	*0.2*	-	-
1638	epi-α-cadinol	t	t	t	t	-	0.9
1640	epi-α-muurolol	t	t	t	t	-	0.8
1644	α-muurolol	-	-	-	-	-	0.3
1645	cubenol	t	t	0.1	t	-	-
1649	β-eudesmol	-	-	-	-	-	1.1
1652	α-eudesmol	-	-	-	-	-	1.0
1653	α-cadinol	t	t	t	t	-	-
1661	sesquiterpene 85,57,41,238	1.1	0.9	1.0	1.2	1.3	-
1668	*β-atlantone*	*0.7*	*0.5*	*0.6*	*0.7*	*0.8*	-
1688	shyobunol	-	-	-	-	-	3.7
1700	eudesm-7(11)-en-4-ol	-	-	-	-	-	0.3
1713	*cedroxyde*	-	-	*0.1*	*t*	-	-
1792	β-eudesmol acetate	-	-	-	-	-	0.2
1987	manoyl oxide	t	0.2	0.1	t	-	0.6
2055	abietatriene	t	0.4	t	t	t	t
2087	abietadiene	-	-	-	-	0.2	0.1
2181	sandaracopimarinal	-	-	-	-	-	0.1
2298	4-epi-abietal	0.2	0.2	0.2	t	t	0.7
2401	abietol	-	-	-	-	-	0.1

KI = linear Kovats Index on DB-5 column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.

Table 2. Variation in cedrol (% total oil) among individual trees in populations of *J. excelsa*. Note that the Cyprus value for cedrol is from bulked leaves from 5 trees.

Bulgaria	22.1	24.4	24.4	26.0	28.2
Greece	18.8	23.0	28.0	35.8	
Eskisehir	11.3	22.1	27.6		
Afqa, Lebanon	14.7	18.2	25.1		
Cyprus	27.5				

Table 3. Variation in cedrol (% total oil) among individual trees in populations of *J. polycarpos* and *J. p.* var. *turcomanica*.

J. polycarpos var. *polycarpos*					
Armenia	26.0	30.2	34.3		
Azerbaijan, hi cedrol	24.8	29.1	30.0	33.1	34.4
Azerbaijan, low cedrol	0.0	0.01	0.01	0.02	0.03
El Njass, Lebanon	0.0	0.01	0.01	0.01	
J. polycarpos var. *turcomanica*					
Kopet Mtns., Turkmenistan	0.1	0.1	0.2		
Fasa, Iran (introgressed)	0.0	0.1	1.1	10.1*	13.8*

*hybrid or introgressed from *J. seravschanica*?

Table 4. Leaf essential oils from populations of *J. polycarpos* , (El) Njass, Lebanon, *Adams 14158-14161*; Armenia, *Adams 8761-8763*, Azerbaijan, high cedrol, Adams 14162, 14165, 14167, 14168, 14171, low cedrol, Adams 14163, 14164, 14166, 14169, 14170; *turco* - *J. p.* var. *turcomanica Adams 8758-90,* Turkmenistan; serav - *J. seravschanica*, *Adams 8483-85*, Pakistan; excel - *J. excelsa*, *Adams 9433-35,* Eskisehir, Turkey. Components from cedarwood oils are highlighted in italics.

		turco.	*J. polycarpos* var. *polycarpos*				*excelsa*	*serav.*
KI	Compound	Turkm lo ced	Njass lo ced	Azer lo ced	Azer hi ced	Armenia hi ced	Turkey hi ced	Pakist hi ced
926	tricyclene	0.1	0.1	0.2	0.1	0.1	0.2	0.1
931	α-thujene	t	t	-	t	t	-	0.4
939	**α-pinene**	**45.0**	**55.6**	**62.4**	**45.5**	**39.9**	**41.7**	**19.9**
953	α-fenchene	0.1	0.2	0.1	0.1	t	0.3	0.1
953	camphene	0.2	0.3	0.4	0.3	0.2	0.2	0.2
957	thuja-2,4(10)-diene	t	0.1	0.1	t	t	0.1	-
961	verbenene	t	-	-	-	t	t	t
976	sabinene	0.3	t	0.2	0.2	0.4	0.1	0.5
980	β-pinene	0.8	0.8	0.9	0.7	0.5	0.7	0.9
991	myrcene	1.9	1.5	2.5	2.0	1.3	1.2	27.4
1005	α-phellandrene	-	t	t	t	-	0.1	0.1
1011	**δ-3-carene**	**t**	**2.1**	**2.3**	**0.4**	**t**	**5.3**	**0.8**
1018	α-terpinene	t	t	0.1	t	t	0.1	0.1
1026	p-cymene	0.2	0.2	0.2	0.1	0.2	0.6	0.6
1031	limonene	1.0	1.0	1.1	1.4	1.0	1.2	1.4
1031	β-phellandrene	0.8	1.0	1.0	0.9	0.4	0.9	1.3
1050	(E)-β-ocimene	-	-	t	t	-	t	t
1062	γ-terpinene	0.4	0.3	0.5	0.4	0.3	0.5	1.0
1068	cis-sabinene hydrate	t	t	t	t	t	t	0.2
1088	**terpinolene**	**0.8**	**0.8**	**1.2**	**0.8**	**0.6**	**1.1**	**0.8**
1098	linalool*	t	0.4	0.5	0.5	0.1	-	0.8
1116	3-methyl butanoate, 3-methyl-3-butenyl-	0.1	t	0.1	0.2	-	t	-
1121	cis-p-menth-2-en-1-ol	-	-	-	-	-	0.1	-
1125	α-campholenal	0.2	0.2	0.4	0.3	0.3	0.5	0.1
1139	trans-pinocarveol	0.2	0.2	0.2	0.2	0.2	0.8	t
1140	cis-verbenol	t	0.1	0.1	0.1	t	0.2	-
1143	camphor	1.0	0.3	0.9	0.4	-	1.2	-
1143	**trans-verbenol**	**-**	**0.4**	**0.8**	**0.5**	**1.1**	**-**	**0.3**
1148	camphene hydrate	t	t	t	t	-	0.1	-
1159	p-mentha-1,5-dien-8-ol	0.1	t	0.2	0.1	t	0.1	t
1160	pinocarvone	-	t	0.1	0.1	-	-	-
1165	borneol	-	0.2	-	-	-	-	-
1172	cis-pinocamphone	-	-	-	-	t	0.2	-
1177	terpinen-4-ol	t	t	0.1	t	t	0.1	0.4
1179	**naphthalene**	**0.6**	**-**	**-**	**-**	**0.2**	**0.1**	**-**
1183	p-cymen-8-ol	t	t	t	t	t	0.1	-
1189	α-terpineol	t	t	0.1	t	t	t	t
1193	4Z-decenal	-	0.1	0.2	0.1	-	-	-
1195	myrtenol	-	0.1	0.2	t	-	-	-
1204	verbenone	0.1	0.1	0.2	0.1	0.2	0.2	t
1217	trans-carveol	t	0.1	0.2	0.1	t	0.2	-
1243	hexyl 3-methyl butanoate	0.4	t	0.2	t	0.2	-	t
1252	piperitone	-	-	-	-	-	0.1	-
1257	**4Z-decen-1-ol**	**-**	**0.2**	**0.2**	**0.1**	**-**	**-**	**0.1**
1285	bornyl acetate	0.3	0.3	0.5	0.3	0.4	0.4	0.4
1290	trans-sabinyl acetate	-	-	-	-	-	-	0.2
1315	(2E,4E)-decadienal	t	-	0.1	-	-	2.4	0.3
1319	(2E,4E)-decadienol	-	-	0.1	-	-	-	-

		turco.	*J. polycarpos* var. *polycarpos*				*excelsa*	*serav.*
KI	Compound	Turkm lo ced	Njass lo ced	Azer lo ced	Azer hi ced	Armenia hi ced	Turkey hi ced	Pakist hi ced
1320	phenolic 149,91,77,164	-	-	0.1	-	-	-	-
1339	**δ-elemene**	**0.1**	**0.2**	**0.1**	**t**	**t**	**-**	**t**
1376	α-copaene	0.1	0.1	t	t	-	-	t
1382	hexyl n-hexanoate	0.1	-	0.2	0.1	0.2	-	0.2
1383	β-bourbonene	-	0.1	t	t	-	0.1	-
1389	β-elemene	0.2	0.2	-	t	-	-	t
1389	β-cubebene	t	-	-	-	0.1	0.1	-
1409	*α-cedrene*	*0.1*	-	-	*0.7*	*1.0*	*0.8*	*0.6*
1413	*β-funebrene*	-	-	-	*0.7*	*1.5*	*0.7*	*0.7*
1418	(E)-caryophyllene	0.6	0.7	0.4	-	0.8	-	0.3
1418	*β-cedrene*	*t*	-	-	*0.6*	*0.2*	*0.5*	*0.2*
1429	*cis-thujopsene*	-	-	-	*0.4*	*0.4*	*0.3*	*0.2*
1434	γ-elemene	t	0.2	-	-	-	-	-
1446	cis-muurola-3,5-diene	t	-	-	0.1	-	0.2	-
1449	trans-sibirene	-	-	t	-	-	-	-
1454	α-humulene	0.2	0.1	t	-	-	0.1	t
1458	(E)-β-farnesene	-	-	-	0.2	0.3	0.2	0.2
1461	cis-muurola-1(6),4-diene	0.2	-	t	0.1	0.1	-	t
1466	*β-acoradiene*	-	-	-	*0.1*	*0.2*	*0.1*	*t*
1473	trans-cadina-1(6),4-diene	-	t	t	0.1	-	0.2	-
1477	γ-muurolene	0.3	0.2	0.1	-	-	-	t
1480	germacrene D	1.3	1.1	0.8	0.3	0.6	0.6	0.3
1489	β-selinene	-	0.2	-	-	-	-	-
1491	trans-murrola-4(14),5-diene	0.2	-	0.3	0.3	-	0.2	0.2
1493	**epi-cubebol**	**0.5**	**0.5**	**-**	**0.1**	**-**	**0.3**	**-**
1498	*β-alaskene*	-	-	-	*0.1*	-	-	-
1494	bicyclogermacrene	-	-	-	-	0.3	-	t
1499	α-muurolene	0.7	0.4	0.3	-	-	0.1	0.2
1502	cuparene	-	-	-	-	-	0.1	t
1503	germacrene A	0.2	0.1	-	-	-	-	-
1505	*α-cuprenene*	-	-	-	*0.1*	-	-	-
1509	β-bisabolene	-	-	-	t	t	0.1	t
1513	*α-alaskene*	-	-	-	*0.5*	*0.1*	*0.2*	*0.3*
1513	γ-cadinene	1.7	1.4	1.2	-	1.0	-	0.7
1513	cubebol	-	-	-	0.6	-	0.4	-
1524	δ-cadinene	2.8	1.6	1.4	0.4	0.8	0.5	0.8
1532	(E)-γ-bisabolene	-	-	-	-	0.3	0.2	-
1532	*γ-cuprenene*	-	-	-	*0.2*	-	*0.2*	*t*
1537	α-cadinene	0.4	0.3	0.2	-	-	-	0.1
1549	elemol	0.7	1.2	1.3	0.4	0.4	-	0.9
1556	germacrene B	2.8	3.6	1.9	0.8	1.6	-	0.7
1561	(E)-nerolidol	-	0.1	0.1	-	-	-	-
1574	**germacrene D-4-ol**	**8.9**	**4.0**	**3.7**	**1.0**	**1.5**	**-**	**2.9**
1582	caryophyllene oxide	-	0.3	t	-		-	-
1587	***allo-cedrol***	***-***	***-***	***-***	***1.9***	***2.3***	***1.9***	***1.2***
1594	ethyl dodecanoate	-	0.3	-	-	-	-	-
1596	***cedrol***	***0.2***	-	***-***	***27.2***	***30.3***	***25.4***	***22.7***
1606	β-oplopenone	0.4	0.4	0.2	-	-	t	-
1618	**junenol**	**-**	**0.5**	**0.2**	**-**	**-**	**-**	**-**
1622	sesquiterp.67,134,174,202	-	1.0	-	-	-	-	-
1627	1-epi-cubenol	-	-	-	-	-	0.5	-
1628	sesquiterp.43,119,161,204	-	-	0.3	0.6	-	-	-
1630	γ-eudesmol	-	0.3	t	-	0.4	-	-
1638	epi-α-cadinol	1.4	0.8	0.8	0.2	0.2	t	0.4
1640	epi-α-muurolol	1.4	0.9	0.7	0.1	0.3	t	0.4

		turco.	*J. polycarpos* var. *polycarpos*				*excelsa*	*serav.*
KI	Compound	Turkm lo ced	Njass lo ced	Azer lo ced	Azer hi ced	Armenia hi ced	Turkey hi ced	Pakist hi ced
1645	α-muurolol	0.5	0.3	0.2	t	t	t	0.1
1649	β-eudesmol	0.2	0.8	0.4	0.1	t	-	0.2
1652	α-eudesmol	t	1.0	0.9	0.2	0.2	-	0.2
1653	**α-cadinol**	**3.6**	**1.1**	**0.8**	**0.2**	**0.5**	**t**	**1.0**
1661	sesquiterpene 85,57,41,238	t	-	-	-	-	1.0	-
1663	β-atlantone	-	-	-	-	-	0.6	-
1666	bulnesol	0.2	-	-	-	0.3	-	0.2
1666	(2E,4E)-decadienol	-	-	-	-	-	0.6	-
1688	shyobunol	2.1	3.7	2.9	1.0	1.2	-	1.6
1700	eudesm-7(11)-en-4-ol	-	0.3	0.1	t	-	-	-
1789	8-α-acetoxyelemol	0.1	-	-	-	-	-	t
1792	β-eudesmol acetate		0.2	0.1	t			
1989	**manoyl oxide**	**-**	**0.6**	**0.2**	**0.3**	**0.4**	**0.1**	**0.2**
2054	abietatriene	t	t	0.2	0.2	t	0.1	t
2080	abietadiene	0.7	0.1	1.5	1.0	0.8	0.5	0.3
2147	abieta-8(14),13(15)-diene	t	-	-	-	-	-	-
2184	sandaracopimarinal	0.1	0.1	t	t	-	-	-
2288	**4-epi-abietal**	**1.9**	**0.7**	**0.9**	**0.9**	**1.5**	**0.2**	**1.2**
2312	abieta-7,13-dien-3-one		-	0.2	0.1			
2331	trans-ferruginol		-	0.1	0.1			
2401	abietol		0.1	0.1	0.1			

KI = linear Kovats Index on DB-5 column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.

Table 5. Comparison of major components by total oil vs. oil minus cedarwood oil components for *J. polycarpos*, hi-cedrol populations. Total concentration (%) of cedarwood oil components:
Azer hi ced: 31.5%, correction factor = 1.315; Armenia hi ced: 35.7%; correction factor = 1.357.

		turco.	*J. polycarpos* var. *polycarpos*			
KI	Compound	Turkm lo ced	Njass lo ced	Azer lo ced	Azer hi ced	Armenia hi ced
	concentration as % total oil					
939	α-pinene	45.0	55.6	62.4	45.5	39.9
1524	δ-cadinene)	2.8	1.6	1.4	0.4	0.8
1556	germacrene B	2.8	3.6	1.9	0.8	1.6
1574	germacrene D-4-ol	8.9	4.0	3.7	1.0	1.5
1652	α-eudesmol	t	1.0	0.9	0.2	0.2
1688	shyobunol	2.1	3.7	2.9	1.0	1.2
	concentration without cedrol, etc.					
939	**α-pinene**	**45.0**	**55.6**	**62.4**	**59.8**	**54.1**
1524	δ-cadinene	2.8	1.6	1.4	0.5	1.1
1556	**germacrene B**	**2.8**	**3.6**	**1.9**	**1.1**	**2.2**
1574	germacrene D-4-ol	8.9	4.0	3.7	1.3	2.0
1652	α-eudesmol	t	1.0	0.9	0.3	0.3
1688	**shyobunol**	**2.1**	**3.7**	**2.9**	**1.3**	**1.6**